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EXPLODING WIRES, FILMS, AND RIBBONS

Annotated Bibliography

(Work Assignment 34, Task 4)

Aerospace Information Division
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FOREWORD

This bibliography, prepared in response to Work Assignment No. 34, Task 4, is intended as a guide to Soviet literature on electrically exploded conductors. It has been compiled from six Soviet journals, spanning the period March 1957 to January 1963, available at the Aerospace Information Division.

The eleven entries are arranged alphabetically by author. An annotation is provided for each article.

Library of Congress call numbers, where available, are given for each journal the first time it is employed as a source.

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INTRODUCTION

Fourteen Soviet periodical titles, covering the period 1956 to date, have been exploited in the preparation of this report. Search of these sources yielded only about 20 scientific papers of interest, of which half were excluded from the report because they had already been cited in the following American publications:

1. Chace, William G., and Howard K. Moore, eds. Exploding wires. [v. 1.] (Based on the First Conference on the Exploding Wire Phenomenon, April, 1959) New York, Plenum Press, 1959. QC703.C69 1959

2. Chace, William G., and Howard K. Moore, eds. Exploding wires. v. 2. (Proceedings of the Second Conference on the Exploding Wire Phenomenon, held at Boston, November 13-15, 1961) New York, Plenum Press, 1962.

3. Good, Robert C., Jr. Destructive effects of plasmas generated by exploding wires. American Rocket Society. 17th Annual Meeting, Los Angeles, Calif., 13-18 November 1962. Proceedings.

4. Chace, William G., and Eleanor M. Watson. A bibliography of the electrically exploded conductor phenomenon. 3d ed. Optical Physics Laboratory, AFCRL, Hanscom Field, Massachusetts, 1962.

Several research papers dealing directly with the exploding wire phenomenon have appeared quite recently in Soviet open-source literature, which may possibly be taken as an indication of currently increasing activity in this field.

EXPLODING WIRES, FILMS, AND RIBBONS

1. **Andreyev**, S. I., M. P. Vanyukov, and Ye. V. Daniel'. Method of registering the spectrum of a pulse-discharge emission with a time resolution of 10^{-8} sec. Optika i spektroskopiya, v. 13, no. 6, 1962, 863-865. QC350.O68

   A photographic apparatus is described which registers time spectra with a resolution of $\leq$ 20 nanosec. A Kerr cell and high-voltage pulses are used with the apparatus. Light emitted by the discharge is projected, with the use of an optical system and two crossed polaroids, on the oscillograph slit. The Kerr cell transmits about 30% of incident light at voltages of ~ 3000 v. A ferrite element (a brass rod with a ferrite ring), is inserted into the discharge circuit without disturbing the current magnitudes. Examination of the apparatus indicates that 1) the duration of the period during which the shutter may be open can be varied from 1 to 50 nanosec; 2) the time delays of shutter opening in respect to the beginning of a discharge exhibit stability from discharge to discharge and are of ~ 5 nanosec duration; and 3) the shape of the pulse can be maintained through a 100-m cable system (500 nanosec). A spectral graph obtained with the use of a photoelectronic multiplier with a 20-nanosec exposure is given.

2. **Andreyev**, S. I., M. P. Vanyukov, and A. B. Komolov (deceased). Expansion of a spark-discharge channel during a rapid current rise in a discharge circuit. Zhurnal tekhnicheskoy fiziki, v. 32, no. 1, 1962, 57-62. QC1.Z48

   An experiment was undertaken to test the theories of Drabkina (1951) and Braginskiy (1958). Oscillographs with time constants not exceeding 10^{-10} sec were used, along with violet and infrared light filters. It was discovered that 1) the hydrodynamic theory of Drabkina agrees with the experimental data only during the first quarter of the current oscillation period; 2) the Braginskiy theory pertaining to the channel radii agrees well with the experimental data; and 3) 10 to 12 km/sec is the maximum expansion rate of a spark-discharge channel in air.

A three-beam high-speed oscillograph and an electron-optical converter were employed to register current and changes in spark-channel time, respectively. The optical system, which included two objectives with focal lengths of 40 and 50 cm, had a very limited field of vision, and its spectral registration capability was 3900 to 6000 Å.

To measure voltage drop, the channel was subdivided into two sections: a short one located near the rod, and a long one where long sparks were formed. The experiments were made with and without an additional electrode on the short rod. The data obtained without the auxiliary electrode show that 1) three distinctive phases (designated leading, reversed, and final) can be identified by scanning the channel; 2) the maximum leading stage current varies from 20 to 1000 amp; 3) the channel diameters at the end of the leading stage reach magnitudes of 0.5 to 2 mm; and 4) the rate of channel broadening increases with an increase in current gradient in both the leading and final stages. With an additional electrode, channel conductivity σ increases linearly with a linear current increase and is a function of time in the ratio $\sigma = a^{0.71}t$, where a is the gradient of the leading stage and t is time in seconds.

With a gradient of $5.5 \cdot 10^{8}$ amp/sec, channel temperature was calculated at 40,000° K, specific conductivity as 300/ohm·cm, and the ion and electron concentrations, evaluated from the energy equation, as $2 \cdot 10^{18}$ and $4 \cdot 10^{18}/cm^3$, respectively. Ionization was double.

Channel development is similar for gradients greater than $5.5 \cdot 10^{8}$ amp/sec in the leading phase -- a standard selected on the basis of experimental data from the present study and investigations by other writers --, but its broadening velocities and channel parameters are of a higher magnitude. When the current gradient is less than $5.5 \cdot 10^{8}$ amp/sec, the velocities are lower than the speed of sound. Solution of the energy balance equation for a leading current gradient of $3 \cdot 10^{6}$ amp/sec, given a specific plasma conductivity of 100/ohm·cm, yields a plasma temperature of 20,000°K and ion and electron plasma concentrations of $10^{18}/cm^3$.

3. Balashov, I. F., M. P. Vanyukov, V. R. Muratov, and Ye. V. Nilov. Recording cross-section- and time-resolved spark-discharge emission spectra by using an electron-optical converter. Optika i spektroskopiya, v. 9, no. 6, 1960, 790-791.

The feasibility of utilizing the device with emissions from gas discharges, exploding wires, etc., having time exposures ranging from 10^{-7} to 10^{-5} sec is explored. The data show that it can be successfully exploited for the determination of time and space distribution of excited atoms in a spark-discharge channel.

4. Bolotovskiy, B. M. Skin effect in thin films and wires. Zhurnal eksperimental'noy i teoreticheskoy fiziki, v. 32, no. 3, 1957, 559-565.

Impedances of thin films and wires and the application of the kinetic theory to thin conductors are studied. By a "thin conductor" is meant a conductor whose thickness is much less than the free path of an electron in an infinite metal space. By using the Chambers method (1950), differential and integral equations pertaining to the skin effects are derived, and, after certain simplifying conditions are postulated, solved. The solution of the equations show that 1) the ratio l/b is the fundamental parameter under the conditions of a conductive semispace, where l is free path length and b is the classical skin-layer depth; 2) the ratios of wire radii and film thicknesses to field penetration depths are the critical parameters in dealing with thin conductors; and 3) when a conductor cannot be assumed thin and the anomalous skin effect takes place, the conductor impedances can be determined by utilizing approximate solutions.

5. Gorin, B. N., and A. Ya. Inkov. Spark-channel investigation. Zhurnal tekhnicheskoy fiziki, v. 32, no. 3, 1962, 329-337.

Channel expansion of a long spark discharge and channel parameters were investigated by varying the current rate. Because it was not possible to measure directly the voltage drop in the channel, indirect methods were used for measuring the voltage gradients and spark-discharge parameters. A plate—rod combination, with the rod positively charged, was selected. The plate—rod distance varied from 0. 3 to 3. 0 m, the voltage from 1000 to 1800 kv, and damping resistance from 1000 ohm to 70 kohm.

6. **Mak, A. A.** Spark-discharge channel temperature in air. Optika i spektroskopiya, v, 8, no. 2, 1960, 278-279.

Increases in current rate were investigated to determine their effect on channel temperature, which was evaluated from measurements of the relative intensity of lines in the nitrogen spectrum. The data show that temperature is almost independent of current rate variations.

7. **Marshak,** I. S. High-current pulse (spark) discharges in gases used in pulse light sources. Uspekhi fizicheskikh nauk, v. 77, no. 2, 1962, 229-286. QC1.U8

The article, a comprehensive survey with 220 references, has four main subdivisions: electric conductivity of a discharge channel, broadening of a discharge channel, characteristic emissions, and near-electrode phenomena. Although the references to exploding wires are of a generalized nature, the following statements are pertinent. "Artificially increasing the length of the discharge channel...by using a pulse discharge in the vapors of a long exploding metallic wire...permits a substantial reduction of the initial longitudinal electric gradient in the channel." (p. 235) "Similar data [data observed during tubular-pulse-lamp and capillary discharges, can be obtained... in the vapors of a metallic wire exploded electrically." (p. 242) "The empirical formula $\rho = 0.1/\sqrt{E}$ [where E is an electric gradient and ρ is effective resistance], derived from data on the instantaneous resistances of the tubular pulse lamps..., can be coordinated with data on the specific resistivities of plasma generated by short spark discharges and by discharges taking place in the vapors of exploding metallic wires....It can be assumed that the formula satisfactorily reflects data pertaining to the specific resistivities of plasma both for a high-current quasi-stationary spark discharge and for a discharge in the vapors of an exploding wire." (p. 246) "Microspot explosions are to some extent analogous to explosions taking place in exploding thin wires. [In both cases] the electric current is broken during the initial explosion phase as a result of high vapor density,..., which might explain the shift of an emission center to adjacent cathode areas. This mechanism is confirmed by the correspondence between the propagation velocity of the shock waves, computed in accordance with hydrodynamic theory, and Boyle's experimental data [1955]...." (p. 279)

8. Mel'nikov, M. A., and V. I. Obukhov. Oscillographic investigation of exploding wires. Izvestiya vysshikh uchebnykh zavedeniy. Energetika, no. 1, 1963, 99-102.

The influence of internal circuit resistance on the physical phenomena present during the explosion of metallic wires with and without a relatively long circuit cable is investigated. Considerable attention was given to the influence of $R_i/R(t)$ ratios, where R_i is internal generator resistance and $R(t)$ is the resistance of the experimental wire, and to the evaluation of the total energy liberated by an exploding wire up to a certain time t. The following observations are made. 1) An exploding wire absorbs the first portion of the energy in the form of a pulse with a duration of $1.5 \cdot 10^{-7}$ to $15.0 \cdot 10^{-7}$ sec. 2) For small R_i and $R_i/R(t)$, voltage and current increase very rapidly; the voltage then increases slowly to a magnitude of 10 v, while the current decreases slowly. 3) The rate of energy liberation in an exploding wire and the amount of energy absorbed per unit volume increase with a decrease in R_i and $R_i/R(t)$. 4) The quantity of energy absorbed per unit volume is approximately ten times greater than that of the best explosives and the channel discharges in liquids.

9. Vanyukov, M. P., and V. I. Isayenko. Investigation of light produced by electrically exploded thin wires. Zhurnal tekhnicheskoy fiziki, v. 32, no. 2, 1962, 197-201.

Light characteristics were studied experimentally as a function of wire diameter and length. A bank of storage condensers of 20-μF capacitance charged to 10,000 v with a discharge circuit inductance of 0.5 μH and a method for photographic recording were used. The experimental data, comprising numerous photographs of exploding copper wires and spark discharges in air, are presented in two curves giving changes in time delays and in the propagation velocity of a shock wave versus dimensions. They show that 1) the delay between the time the current is switched on and the explosion is proportional to the cross-sectional area of the wire; 2) the larger the cross section and the shorter the length, the greater the growth velocities of the explosion cloud and the luminous channel; 3) the explosion luminescence localized between a shock wave and a dense metal-vapor cloud exhibits a time delay whose duration is relative to the beginning of explosion-product expansion; 4) there is a substantial difference in the development of a luminous channel from exploding wires and from spark discharges in air; and 5) metallic vapor luminescence is localized in hollow cylinders expanding at velocities of 20 to 30 km/sec.

10. Yegorova, V. F., V. I. Isayenko, A. A. Mak, and A. I. Sadykova. Distribution of temperature and electron concentrations in a spark-discharge channel. Zhurnal tekhnicheskoy fiziki, v. 32, no. 3, 1962, 338-345.

Emission intensities of spectral lines and plasma distribution in a spark discharge channel were investigated by using photoelectrical registration and an electron-optical converter. The radial distribution of emission was evaluated by employing the Abel equations. The findings of the study indicate that the distribution of temperature and ion concentrations in the spark channel is uniform and that channel temperature obtained by different experimental techniques are the same, while the differences in electron concentration, as evaluated from the intensity and shift of spectral lines, cannot be explained by channel nonhomogeneities.

11. Preobrazhenskiy, N. G. Light absorption peculiarities in nonhomogeneous plasma. IN: Akademiya nauk SSSR. Doklady, v. 140, no. 4, 1961, 801-804. AS262.S3663

It is believed that the complex phenomena taking place in a nonhomogeneous, high-temperature plasma can be correctly described by using, as the models, the axially symmetrical emitters of Bartels and Cowan-Dicke and by assuming that the plasma phenomena take place in arc and pulse discharges, in hollow cathodes, in exploding metallic wires, and under other conditions. The article is an analytical investigation of the relationship expressed as curves of growth, between the equivalent line width and the optical density of a nonhomogenous absorbing layer. Study of the curves of growth indicates that the whole range of optical densities can be subdivided into five intervals. 1) a region of proportional transfer for $k_0l < 0.5$, k_0l being the optical thickness of a layer; 2) a region for a gradually decreasing slope where $0.5 < k_0l < 3.0$; 3) a region of least slope for $3.0 < k_0l < 15.0$; 4) a region where the "root law" is valid for $15 < k_0l < 100$; and 5) a region where $k_0l > 100$. It is of interest that certain curves of growth demonstrate the presence of anomalous areas where an equivalent line-width decrease corresponds to an increase in optical density. The investigation indicates that generalized curves of growth can be used as a theoretical foundation for the construction of spectroanalytical charts and for various applications in spectroscopy and astronomy.

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